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The research on mechanism of color management system based on iCAM color appearance model☆

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ABSTRACT

Since color recording and color representing abilities of various media are very different, color information is often lost or misrepresented in the process of image transmission and reproduction. A Color Management System (CMS) based on iCAM color appearance model is presented in this paper. It can be used either in computer operation system software or application software for obtaining color consistency across different software applications, imaging devices, imaging media and viewing conditions.

1. Introduction

In the research of computer vision, accurate transmission and reproduction of color information are the premise of the analysis and reproduction of natural sceneries. Since the recording and representing abilities of various media are very different (mainly because different media have different color gamut), color information is often lost or misrepresented in the process of image transmission and reproduction [1].

The function of the Color Management System (CMS) is to guarantee the accurate color transmission and reproduction among different media [10]. The basic mechanism of the current CMS is based on CIE LAB Standard Color Model as shown in Fig. 1. The color information of input media is first transformed into the Standard Color Model CIE LAB [1]. Then according to recording and representing ability of the output media, color gamut mapping is implemented from the input media to the output media in CIE LAB model. Finally, the color information is transformed from CIE LAB model to the output media.

The main problem of using CIE LAB as a Standard Color Model to carry out gamut mapping is: although the CIE LAB color model can render all colors, differences among colors do not conform to human vision. Human eyes' feeling of the color differences is usually denoted by the space distance in the color model. In CIE LAB model, the space distance between colors is different from the perception of human eyes. Generally, the color model which does not conform to human vision is called uneven color model, and it is quite dangerous to carry out gamut mapping in an uneven color model. If it is used to map the color gamut from a big gamut media to a small gamut media, it will not only cause the uneven compression of the gamut, but also cause the color in the sensitive area of human eyesight to wrongly undergo a large-scale compression. Therefore, choosing a proper standard color model as an intermediate color gamut mapping platform is the key technology for correct color information transmission and reproduction among various media [6]. This paper proposes to use iCAM color appearance model as the standard model in CMS and to create a CMS based on iCAM color appearance model. The experiment result has proven that the CMS based on iCAM appearance model is superior to the current CMS based on CIE LAB model.

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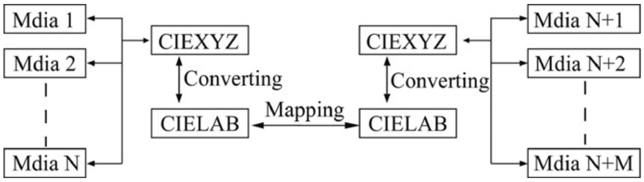

Fig. 1. The mechanism of CIE XYZ-based color management.

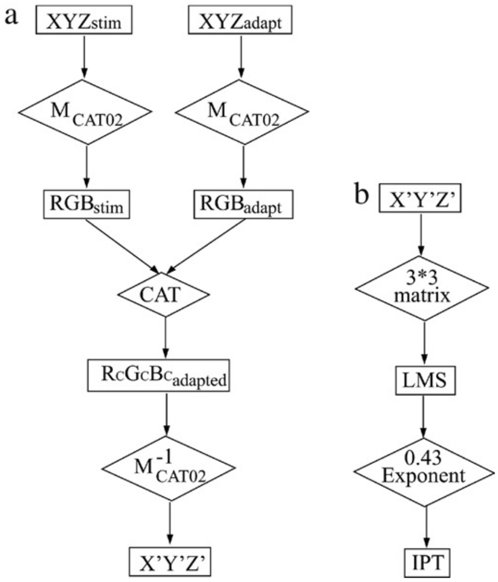

Fig. 2. Flow chart of creating IPT color gamut mapping platform.

2. The characteristics and framework of iCAM

2.1. Characteristics of iCAM

In 2002, Munsell Color Science Lab of Rochester Institute of Technology put forward iCAM (Image Color Appearance Model), which integrates advantages of IPT Color Space (hue uniformity) [2], S-CIELAB Color Space (spatial filter) [3] and CIECAM02 Color Appearance Model (Chromatic Adaptation Transformation) [4,5] whose target is to simultaneously provide traditional color appearance capabilities, spatial vision attributes, and color difference metrics. iCAM has the following characteristics.

Since the consideration of practical viewing conditions has been involved in iCAM, it can accurately predict the result of the observation under different conditions.

Its hue uniformity is excellent. As iCAM can describe aspects of color appearance phenomena including accurate metrics of color differences well, it can be used to carry out the color gamut mapping calculation based on the perception of human eyes.

iCAM considers image's spatial aspects of vision and adaptation. The adapting stimulus becomes a spatially low-pass image. So it is adapted to images.

Therefore, we selected iCAM as the standard color model of CMS. The color gamut mapping calculation from input media to output media can be accomplished in the iCAM. Thus, the computer vision after cross-media transmission is more approximate to human vision.

2.2. The mechanism of creating the color gamut mapping platform [6–8]

The structure of the iCAM standard model is mainly divided into two parts. Firstly, for Chromatic Adaptation Transformation (CAT), the XYZ tristimulus values are converted into CAT02 color space. Then $X'Y'Z'$, which has accomplished the chromatic adaptation are converted into IPT (Image Processing Transform) color space to carry out the gamut mapping calculation. Finally, these values are inversely converted to $X''Y''Z''$. The process of creating the IPT color gamut mapping platform is shown in Fig. 2 [9].

2.2.1. Chromatic adaptation transformation

There are four steps in Chromatic Adaptation Processing:

Step 1. To add the influence of the observation light source and the viewing conditions in color observation, transform the XYZ tristimulus values of an image to the *RGB* image signals by applying the M_{CAT02} matrix;

Step 2. Calculate the adaptation factor D of the observation light source and conditions;

Step 3. Calculate the adaptation signals R_C, G_C, B_C using the low-pass adaptation image at each pixel location (R_w, G_w, B_w), the luminance of the white point Y_W and the adaptation factor D.

Step 4. Calculate the X', Y', Z' derived from the R_C, G_C, B_C by applying the M_{CAT02}^{-1} matrix.

First, transforming the *XYZ* tristimulus values of an image to the RGB image signals

The color space, in which the Chromatic Adaptation Transformation is carried out, is CAT02. The formula of converting the tristimulus values into CAT02 color space is

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = M_{CAT02} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

$$M_{CAT02} = \begin{bmatrix} 0.7328 & 0.4296 & -0.1624 \\ -0.7036 & 1.6975 & 0.0061 \\ 0.0030 & 0.0136 & 0.9834 \end{bmatrix}. \tag{2.1}$$

Second, calculating the adaptation factor D. The description of color appearance should be influenced with an adaptation state of the white-point. To evaluate the adaptation degree, we use the adaptation factor D which varies from 0.0 for no adaptation to 1.0 for complete chromatic adaptation

$$D = F\left[1 - \left(\frac{1}{3.6}\right) \mathrm{e}^{\left(\frac{-L_A - 42}{92}\right)}\right]. \tag{2.2}$$

L_A: adaptation luminance, unit: cd/m^2, the same value as Y_w used in this experiment.

F: adaptation surround, generally 1.0 for average surround, 0.9 for dim and 0.8 for dark.

Third, chromatic Adaptation Transformation (CAT)

CAT is a phenomenon in which cone response RGB values are adjusted

$$\begin{aligned} R_c &= [Y_w D/R_w + (1 - D)]\, R \\ G_c &= [Y_w D/G_w + (1 - D)]\, G \\ B_c &= [Y_w D/B_w + (1 - D)]\, B \end{aligned} \tag{2.3}$$

Y_w: white-point luminance

R_w, G_w, B_w: tristimulus responses for the adapting white-point

D: adaptation factor

R, G, B: tristimulus of cone responses in CAT02 color space

R_c, G_c, B_c: tristimulus of cone responses after chromatic adaptation transformation

After CAT, converting *TRIALRESTRICTION* from R_c, G_c, B_c

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = M_{CAT02}^{-1} \begin{bmatrix} R_c \\ G_c \\ B_c \end{bmatrix}$$

$$M_{CAT02}^{-1} = \begin{pmatrix} 1.096214 & -0.278869 & 0.182745 \\ 0.454369 & 0.473533 & 0.072098 \\ -0.009628 & -0.005698 & 1.015326 \end{pmatrix}. \tag{2.4}$$

So, the R_c, G_c, B_c values of CAT02 are converted into *XYZ* color space again.

2.2.2. IPT transformation and gamut mapping

Transforming *TRIALRESTRICTION* to cone response space by using a $3 * 3$ matrix

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} 0.4002 & 0.7075 & -0.0807 \\ -0.2280 & 1.1500 & 0.0612 \\ 0.0000 & 0.0000 & 0.9184 \end{bmatrix} \begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} \tag{2.5}$$

$X'Y'Z'$: tristimulus values implemented through the CAT calculation

L, M, S: tristimulus of cone responses

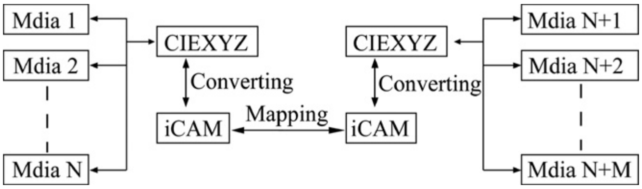

Fig. 3. The mechanism of iCAM-based color management.

Adjusting tristimulus of cone responses by using power-function, generally, the basic power-function of adjusting cone responses is exponential (0.43).

$$\begin{aligned}
&L' = L^{0.43}; \quad L \geq 0\\
&L' = -|L|^{0.43}; \quad L \leq 0\\
&M' = M^{0.43}; \quad M \geq 0\\
&M' = -|M|^{0.43}; \quad M \leq 0\\
&S' = S^{0.43}; \quad S \geq 0\\
&S' = -|S|^{0.43}; \quad S \leq 0.
\end{aligned} \tag{2.6}$$

Linear transform to IPT color space

$$\begin{bmatrix} I \\ P \\ T \end{bmatrix} = \begin{bmatrix} 0.4000 & 0.4000 & 0.2000 \\ 4.4550 & -4.8510 & 0.3690 \\ 0.8065 & 0.3572 & -1.1628 \end{bmatrix} \begin{bmatrix} L' \\ M' \\ S' \end{bmatrix}. \tag{2.7}$$

As the platform of IPT is a color space that excessively accords with human vision, calculation of all kinds of gamut mapping can be done expediently in it.

3. Construct CMS based on iCAM

3.1. The general design of CMS based on iCAM

The key technology of the study is to build a CMM (Color Management Module) software platform to accomplish gamut mapping. The mechanism of color management based on iCAM is shown in Fig. 3:

First, color information of input media is transformed to CIE XYZ according to the input profiles. Input profiles provide necessary transforming data through which color information of input media can be transformed to CIE XYZ standard color model.

Second, CIE XYZ color data of the image are converted to CAT02 color space, and then to IPT color space. Gamut mapping is implemented in IPT color space. After gamut mapping, the data are reversely transformed to the CIE XYZ color space, which is transformed to output media according to output profiles.

The images are displayed in Adobe Photoshop software.

3.2. The development of CMM [10]

The improved CMM is developed in Microsoft VC++ 6.0. The operation interface of the program is shown in Fig. 4:

The major functions are as follows.

The upper-left is the source image selection. The image file of input media must be attached with the input media profile, which offers the transform relationship between media color information and CIE XYZ. After choosing the source image, CMM will perform functions as follows.

(1) Read the data of the image
(2) Read the attached profile and display the description of the attached profile on the interface
(3) Transform the color data of the image from the input media to CIE XYZ according to the attached profile.
(4) Transform the CIE XYZ tristimulus values of the image to iCAM representation.
(5) Calculate the gamut of the image in IPT color space.

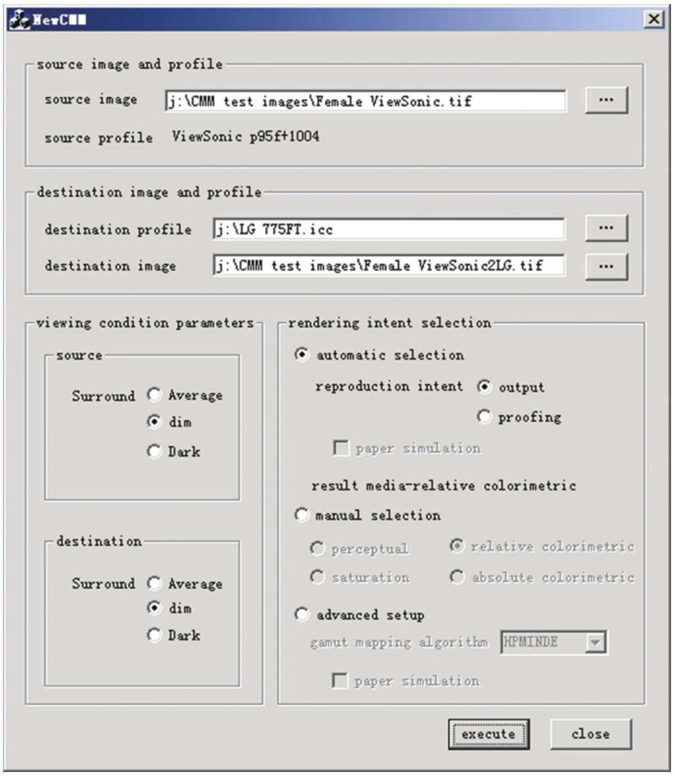

Fig. 4. The improved CMM developed in Microsoft VC++ 6.0.

Fig. 5. Compare the output images by the improved CMS and the old CMS.

Below source image is the selection of the destination image and destination profile. After selecting the destination profile, the destination gamut in IPT color space is calculated.

At the bottom of the user interface, the parameters of color conversion can be set up. The left are parameters of viewing conditions, including the source and destination surround. The middle are the choices of rendering intent, which can be chosen either automatically or manually.

After all the parameters are setup, click the "execute" button and CMM will complete the following procedures.

First, implement color gamut mapping from the input media to the output media in IPT color space.

Second, the IPT' data of the image gamut mapped is inversely transformed to CIE XYZ and converted to the output color data according to the output profile.

Finally, the destination image is saved with the destination profile attached.

4. Analyze and evaluate

In order to evaluate the precision of CMS based on iCAM, 14 images have been tested, including 6 testing images made by GATFFemale.tif, Grey Neutrals.tif, Memory Colours.tif, Painting Kids.tif, Red Couch.tif, Wedding.tif; 4 ISO 12640 standard images (Fruit.tif, Vessel.tif, Musician.tif, N6A.tif); 2 graphics (Beetle.tif, Color strip.tif) ; rainbow.tif and Ski.tif. These images test every aspect of image reproduction, such as shadow, highlight, neutral gray, memory color and saturation.

S-CIELAB color difference formula was adopted to calculate image color differences. The results of the Color Differences between the originals and the output images based on the improved CMS and the old CMS are compared in Table 1.

Table 1
Comparision of the color differences between the improved CMS and the old CMS.

Images	Color differences of the improved CMS	Color differences of the old CMS
Female.tif	0.7482	0.7533
Grey neutrals.tif	0.941	0.959
Memory colours.tif	0.9287	0.9328
N6A.tifd	0.8791	0.8591
Painting kids.tif	1.394	1.485
Red couch.tif	1.719	2.037
Musician.tif	1.434	1.658
Wedding.tif	0.8967	1.002
Color strip.tif	2.18	1.299
Vessel.tif.tif	0.967	0.9205
Fruit.tif	1.334	1.599
Beetle.tif	3.102	4.674
Ski.tif	10.56	17.79
Rainbow.tif	4.346	5.163
Average color difference	2.245	2.938

Ten people observed the results and made comparative judgments. The results show that the iCAM-based CMM is superior to the color management based on CIE LAB. In Fig. 5, the left is the result of the improved CMS. The middle is the original image rainbow.tif and the right is the result of the old CMS. Rainbow.tif is very difficult to reproduce and can be used to detect the reproduction quality. It is obvious that the image reproduced by the new CMM is almost the same as the original, while the image by the old CMM has several dark lines.

5. The conclusion

In this experiment, a platform is made for accomplishing color gamut mapping between outputting and inputting media by applying the technology of the iCAM Standard Color Model. This model is a very even color model similar to human vision. Both subjective and objective evaluations of the results of the reproduction images show that, the color gamut mapping based on iCAM appears better than the one based on CIE XYZ, especially in the cross-media images reproduction, High-dynamic-range images reproduction and so on.

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